<table>
<tr><td>ORAU Team
Dose Reconstruction Project for NIOSH

Technical Basis Document for the Idaho National Engineering and Environmental Laboratory (INEEL) - Occupational Medical Dose</td><td>Document Number:
ORAUT-TKBS-0007-3
Effective Date: 05/28/2004
Revision No.: 00 PC-1
Controlled Copy No.: ________
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None</td></tr>
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RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
Draft	08/31/2003	00-A	New Technical Basis Document for the Idaho National Engineering and Environmental Laboratory (INEEL) - Occupational Medical Dose. Initiated by Norman Rohrig.
Draft	09/23/2003	00-B	Incorporates changes in response to NIOSH and ORAU comments. Initiated by Norman Rohrig.
Draft	11/12/2003	00-C	Incorporates additional changes in response to NIOSH and ORAU comments. Initiated by Norman Rohrig.
Draft	11/26/2003	00-D	Incorporates changes in response to DOL comments. Initiated by Norman Rohrig.
01/15/2004	01/15/2004	00	First approved issue. Initiated by Norman Rohrig.
01/15/2004	05/28/2004	00 PC-1	Adds spleen to organ table on page 10. Eliminates date overlap in table on page 11. Initiated by Norman Rohrig. Approval: Signature on File 05/27/2004 Document Owner, Norman Rohrig, TBD Team Leader Signature on File 05/27/2004 Task 3 Manager, Judson Kenoyer, Task 3, Manager Signature on File 05/27/2004 Richard E. Toohey, Project Director Signature on File 05/28/2004 James W. Neton, OCAS Health Science Administrator

ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AP	Anterior-Posterior
cm	centimeter
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
ICRP	International Commission on Radiological Protection
INEEL	Idaho National Engineering and Environmental Laboratory
IREP	Interactive RadioEpidemiological Program
KERMA	Kinetic Energy Released to Matter
kg	kilogram
kV	kilovolt
kVp	kilovolt peak
lat	lateral
lb	pound
mA	milliampere
mm	millimeter
mrad	millirad
msec	millisecond
PA	Posterior-Anterior

3.1 INTRODUCTION

This section discusses the occupational medical dose workers received during employment at INEEL (Idaho National Engineering and Environmental Laboratory). The site required preemployment and periodic physical examinations as part of its occupational health and safety program. At first, the Atomic Energy Commission (AEC) provided these medical examinations for all contractors and AEC personnel. Later, the service became the responsibility of the site prime contractor.

The examinations typically included diagnostic chest X-rays. The dose from these procedures depended not only on the characteristics of the X-ray machine and the procedure used, but also on the frequency of examinations. This section discusses the various X-ray techniques and equipment used over the years at the INEEL. Attachment 3A contains tables for use by dose reconstructors in determining a worker's occupational medical dose. The primary source of information on medical X-rays is a report by Collings and Creighton (2002) prepared at National Institute for Occupational Safety and Health EEOICPA request.

3.2 EXAMINATION FREQUENCIES

Collings and Creighton (2002) reported that from 1954 to 1970 chest X-rays were performed on new hires and on radiation workers at ages 25, 30, 34, 37, and 40, every 2 years from ages 40 to 62, and then every year. They also reported that all employees went on this schedule in 1970. A somewhat contradictory schedule is reported in the 1960 Annual Report (AEC 1961) as noted in the following table:

Age	Radiation area employees Badged	Nonradiation employees Nonbadged
18-24	4 years	At age 30
25-39	3 years	5 years
40-49	2 years	3 years
50-59	1 year	2 years
Over 60	1 year	1 year

This schedule is corroborated by a John Sommers memorandum (Sommers 1961). We assume that the 1960 schedule applies to dose reconstruction for all workers in the 1954 to 1970 period because it involved more examinations and is thus claimant-favorable.

The Appendix to AEC Manual Chapter 0528 (AEC 1969) specified the following:

- A chest X-ray would be part of a medical examination.
- Workers under 40 would receive an exam at a frequency influenced by several factors.
- Workers over 40 would receive an exam at least every 2 years (approximately annually when indicated).

The schedule in the table is consistent with that requirement except for ages 40 to 49. The 1971 Annual Report (AEC 1972) states the schedule for examinations is "at time of hire, at ages 25, 30, 34, 37, and 40, every two years until age 62 and then annually." This is identical to that reported by Collings and Creighton (2002) and is assumed to apply from 1970 to 1976.

Beginning in 1976, physicals occurred every 2 years for workers under age 45 and every year for those over age 45 (Collings and Creighton 2002). On February 1, 1978, routine chest X-rays were eliminated on periodic physicals except for high-risk (as determined by the physician) individuals, in which case they were performed every 4 years. Records from the exposures are reported in each worker's medical file.

3.3 EQUIPMENT AND TECHNIQUES

The standard distance from source to image was 72 inches (183 cm).

To the best of our knowledge, none of the INEEL exams used fluoroscopic techniques (Creighton 2003; Spickard 2003). In the 1971 Annual Report, a medical van is identified as taking 22% of the 4,426 X-ray examinations. Also mentioned is the Idaho Falls Navy dispensary for doing X-ray examinations. Both of these facilities performed standard chest X-rays (Spickard 2003) and did not do photoflouroscopy. A key word search of the INEEL records system using the words collimation, fluoroscopic, Health and Safety, Health and Safety Services, Medical X-ray, photofluorography, and x-ray resulted in nothing indicating use of fluoroscopic techniques (Vivian and Rockhold 2003).

From 1954 to February 1990, X-ray examinations were performed with a single-phase General Electric Model DXD350 machine. The voltage was 90 kVp, the current was 300 mA, and the duration of the exposure was 1/15 sec (67 msec). Added filtration of 2 mm aluminum was used, and a 10:1 grid was used to reduce scatter radiation (Collings and Creighton 2002). Tube window thickness is assumed to be about 0.5 mm. Based on Table A16 of *Protection of the Patient in Diagnostic Radiology* (International Commission on Radiological Protection Publication 34; ICRP 1982), the half-value layer at 90 kVp and 2.5 mm total aluminum filtration is 2.58 mm Al.

From February 1990 to the present, X-rays have been performed with a three-phase Gendex Model 110-0030G2. The voltage was 100 kVp, the current was 300 mA, and the duration was 32 msec. Added filtration of 2 mm aluminum was used, and a 10:1 grid was used to reduce scatter radiation (Collings and Creighton 2002). Tube window thickness is assumed to be about 0.5 mm. Based on Table A17 of ICRP (1982), the half-value layer at 100 kVp and 2.5 mm total aluminum filtration is 3.3 mm Al.

Practices before 1954 are unclear. Offsite facilities might have been contracted to perform the examinations. The default value for entrance kerma of 200 mrad (Kathren 2003) is assumed for that period.

From 1954 to 1970, the chest X-ray consisted of a single posterior-anterior (PA; back to front) image. From 1970 to 1978, the procedure consisted of both PA and lateral views. From 1978 to 1990, the lateral view was dropped and only a PA view was made. For the latest period from 1990 to the present, there was both PA and lateral views. For lateral views, the exposure time was about 1.25 times that of the PA view. In Collings and Creighton (2002), the terms PA and AP (anterior-posterior, front to back) appear somewhat interchangeably. Creighton attributed this presumed interchangeable usage to a typographical error. The August 21, 1975, Energy Research and Development Administration requirement for occupational medical programs (replaced in 1982) specified the minimum requirements for chest X-rays and specified a PA view at least once every 5 years, as well as when transferring to a job with cardiorespiratory system stress (ERDA 1975).

Collimation and control of scatter for the INEEL facilities generally followed the state of the medical art as it improved. However, in absence of particular information about collimation, we will use the dose conversion factors in Table 4.0-1 of Kathren (2003) for the pre-1970 time frame.

3.4 ORGAN DOSES

The entrance air kerma for 100 mA sec can be determined from Table B3 of National Council on Radiation Protection and Measurements Report No. 102 (NCRP 1989) and the beam voltage, distance, and total filtration. Tables A2 to A9 of ICRP (1982) list Monte Carlo calculation results of the ratio of organ doses to air kerma, for a 70-kg (154-lb) male or female, for the thyroid, ovaries, testes, lungs, female breast, uterus (embryo), active bone marrow, and total body under different exposure conditions. For organs where there is a difference for males and females, the larger value is used to be claimant favorable. A linear interpolation, applicable to the pre-1990 and post-1990 years, was used between the dose ratios for half-value layers of 2.5, 3.0 and 3.5 mm Al to the values of 2.58 and 3.3 mm Al. The skin entrance surface was assumed to be 30 cm from the film for the PA view and 40 cm from the film for the lateral view. These distances account for body thickness and any other space between the person and the film. The dose to the skin is the product of the entrance skin exposure and a backscatter factor taken from NCRP 102 Table B-8.

The organ dose from a PA image is the product of the two table values, an inverse square correction, and the product of exposure current and time. Table 3A-1 lists these values. For lateral images, a similar calculation was performed and added to the PA result.

Under the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) of 2000 (Public Law 106-398), cancers in several other organs are compensable, as listed in the Interactive RadioEpidemiological Program (IREP). The ratio of doses for two organs is affected by the relative atomic numbers of the tissue (bone dose is higher than dose in nearby muscle), the relative positions of the organ and the X-ray beam, and the depth in the body. Attachment 3A lists these other organs and the organs from ICRP (1982), which were used to estimate the dose. Table 3A-1 features these organs in the third row.

3.5 UNCERTAINTY

Uncertainties in the occupational medical dose result from uncertainties in the current, voltage, and time for the exposures. The organ doses are also influenced by the size of the person. For IREP organs where an analog organ is used from the ICRP (1982) organs, the IREP organs are generally deeper in the body so the dose will be lower than the analog organ. No estimate is made of this one-sided uncertainty because it cannot lead to a larger dose.

The uncertainties assigned in the Savannah River Site Technical Basis Document (ORAU 2003) are generically valid for X-ray programs. The uncertainty at one sigma due to voltage was 9 percent, that due to current was 5 percent, and that due to time was 25 percent. The uncertainty for voltage assumes a 5% voltage uncertainty and since the output has a $V^{1.7}$ dependence results in a 9 % uncertainty. Output is directly proportional to current which is assumed to have a 5 % uncertainty. The usually unfiltered voltage output from the voltage rectifier cause a pulsed character to the x-ray output at 120 Hz (twice the supply frequency). For the short exposure times this results in only a few pulses and thus a fairly large uncertainty due to time.

All Monte Carlo calculations have an uncertainty determined by the length of the run and the number of events scored for each calculation. For the organ dose calculations from ICRP 34, this uncertainty was not stated. Based on judgment, it is assumed to be 5% at 1 sigma which would require at least 400 counts in each scoring unit.

The error due to patient thickness has two causes: (1) an increase for a larger person being closer to the source and (2) a decrease due to additional attenuation in the body. The Monte Carlo calculations in ICRP (1982) assumed 70-kg (154-lb) male and female geometries. The 10% uncertainty assigned in the Savannah River Site Technical Basis Document was due to the first cause; but, because the effects counteract, that value is appropriate for the combined effect. This should be taken as 1 sigma on a normal distribution. These sources of uncertainty added in quadrature result in a combined uncertainty of ±30 % at 1 sigma or 84% confidence.

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GLOSSARY

Atomic Energy Commission
Original agency established for nuclear weapons and power production; a predecessor to the U.S. Department of Energy.

Anterior-Posterior
Irradiation geometry in which the radiation passes from the front of a person to the back.

Lateral
Irradiation geometry in which the radiation passes from one side of a person to the other.

Posterior-Anterior
Irradiation geometry in which the radiation passes from the back of a person to the front.

rad
The unit for absorbed dose, 1 rad = 100 erg gm^{-1}

X-ray
Ionizing electromagnetic radiation of external nuclear origin or an image generated by exposing a detector (e.g., film) to x-rays.

ATTACHMENT 3A OCCUPATIONAL MEDICAL DOSE

The following are analogs for IREP organs not included in ICRP (1982):

Anatomical Location	ICRP (1982) Reference Organ	IREP Organ Analogs
Head	Thyroid	Eye
		Brain
Thorax	Lung	Thymus
		Esophagus
		Bone surface
		Stomach/Spleen
		Liver/Gall Bladder
Abdomen	Ovaries	Urinary Bladder
		Colon
		Uterus

INEEL conducted initial and periodic X-ray examinations as part of the medical examinations. The skin entrance air KERMA values in mrad are shown below.

Air kerma (mrad)	PA	Lat
Pre 1954	200	200
1954 to 1990	52	74
1990 to present	53	76

Table 3A-1 lists the frequencies and doses. Table row 2 lists the organs identified in ICRP (1982) and table row 3 lists the organs identified in IREP that are not listed in ICRP (1982). The uncertainties at the 84% confidence limit (1 sigma) are ±30 %.

Table 3A-1. Organ doses from occupational medical exposures at the INEEL.

				ORGAN DOSES (mrad) from INEEL Chest X-Ray						
		ICRP 34 Organs		Thyroid	Testes	Lungs	Breast	Ovary Embryo	Bone Marrow	
		Other Organs		Eye Brain		Thymus Esophagus Stomach Bone Surface Liver/Spleen Gall Bladder		Uterus Bladder Colon		Skin
Time Period	Frequency		Geometry							
Before 1954	No information Assume annual		PA	69	1.8	93	10	34	19	272
1954 to 1969		New hires	PA	18	0.5	24	2.7	8	5	70
	Radworkers									
	Every 4 yr	18-24								
	Triennial	25-39								
	Biennial	40 - 49								
	Annual	over 50								
	Non radworkers									
	Every 5 yr	30-39								
	Triennial	40-49								
	Biennial	50-59								
	Annual	over 60								
1970 to 1976		New hires	PA, Lat	10	0.008	41	22	0.1	8	171
	25, 30, 34, 37, 40									
	Biennial	40 to 62								
	Annual	>62								
1977 to 1978		New hires	PA, Lat							
	Biennial	<45								
	Annual	>45								
1979 to Jan 1990	4 years	New hires High risk only	PA	1.8	0.001	24	2.7	0.1	5.0	70
Feb 1990 to present			PA, Lat	14	0.008	53	27	0.3	11	180